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An MCDM approach for selecting green aviation fleet program management strategies under multi-resource limitations

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ABSTRACT

Green aviation fleet management is a proactive method used to enhance environmental protection without exacerbating climate change. The aviation industry needs to improve its aviation fleet management strategies given corporate social responsibility (CSR) policy and environmental considerations. Green aviation fleet management development involves complex relationships with technology, operation, infrastructure and economic performance. Hence, this study proposes a multi-criteria decision making (MCDM) approach which integrates the decision-making trial and evaluation laboratory (DEMATEL), analytic network processes (ANP) and zero-one goal programming (ZOGP) to achieve optimal green aviation fleet management strategy decisions. Our evaluation shows that the proposed mixed strategy portfolio for green aviation fleet management can be determined using limited resources. Moreover, the model developed herein could be applied more widely to various green aviation fleet management situations.

1. Introduction

Climate change and its effect on the environment is an issue currently sparking global concern, particularly in regard to government policy, business strategy and ecological impacts. Advances in technology and industry have made human life more convenient in a number of ways; however, these advances have also resulted in numerous anthropogenic greenhouse gases that contribute to global warming and ecological and environmental degradation. Global warming causes sea levels to rise, and threatens the environment with climate change; as a result, a large number of creatures face becoming endangered species or even extinction. Furthermore, long-term droughts, disastrous floods, blizzards and other extreme weather have occurred throughout the world in recent years. In 2014, World Meteorological Organization (WMO) published the IPCC 5th Assessment Report issued by the Intergovernmental Panel on Climate Change (IPCC). It stated that, from 1951 to 2010 more than half of the factors causing the global average surface temperature to rise are most likely due to the increase in anthropogenic greenhouse gas concentrations and other anthropogenic factors. (Pachauri et al., 2014) If global warming continues to degrade the environment, human life will be subject to a severe threat. Global efforts are being devoted to discovering how to slow down global warming and achieve relevant international environmental agreements.

Due to the impact of globalization, intercontinental transport and subsequent hemispheric air pollution in the ozone layer jeopardize both agricultural and natural ecosystems worldwide and also have a strong effect on the climate (Akimoto, 2003). The aviation industry expends a large amount of fuel in the air, which is why aviation greenhouse gas emissions are considered one of main causes of climate change. Data issued by the IPCC point out that approximately one-fourth of global greenhouse gas results from the transport industries; the aviation industry accounts for 13% of the total transport industry's emissions. For this reason, the International Air Transport Association (IATA) passed a landmark decision in 2008 to adopt a set of ambitious targets: (1) A cap on aviation CO_2 emissions starting from 2020 (carbon-neutral growth), (2) an average improvement in fuel efficiency of 1.5% per year from 2009 to 2020, and (3) a reduction in CO_2 emissions by 50% by 2050, relative to 2005 levels. At a Copenhagen conference in 2009 that

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represented airlines, airports, suppliers, manufactures, etc, the IATA proposed that these collective goals become the future environmental goals for the aviation industry. Since 2012, the Aviation industry has been included in the regulation of European Emissions Trading Scheme (EU ETS), and airline routes have had to comply with limited carbon emission requirements.

At the 39th congress in 2016, the International Civil Aviation Organization (ICAO), which has 191 contracting states, achieved an historic agreement to implement a market-based measure that will support airlines' efforts to stabilize emissions with carbon neutral growth. The ICAO's 191 member states agreed to implement a Carbon Offset and Reduction Scheme for International Aviation (CORSIA) and adopted a resolution: Consolidate ICAO environmental policies and practices in response to climate change. CORSIA is the first global scheme covering an entire industrial sector to encourage contracting states to report on their plans of action; it outlined the policy actions to reduce carbon emissions and to report their international aviation carbon emissions to ICAO annually. To address aviation emissions, the congress also adopted a basic blueprint for developing a market-based mechanism (MBM). The global MBM will be fully finalized in 2016, and will be fully put into practice in 2020. In order to implement and improve the global MBM, the EU has also amended the EU ETS policy on the aviation industry and directed the improvements on EU ETS from 2013 to 2016. In April 2014, the related regulations were put into effect. CORSIA is set to commence with a voluntary period (2021–2026) after which it will become mandatory. For the first voluntary phase now numbers 65, giving CORSIA which estimate will cover more than 80% of growth post 2020.[1]

Green airline fleet planning is considered to be a critical hybrid concept. In order to achieve a set of ambitious targets to mitigate CO_2 emissions from air transport, IATA is determined to be part of the solution, but insists that a strong commitment is required from all stakeholders working together through the four pillars of the aviation industry strategy. The four pillars integrate environmental factors into aviation fleet management through technology, operation, infrastructure and economic performance. Previous research has investigated green airline fleet planning based on an activity-based costing (ABC) decision model under the constraints of the EU ETS (Tsai et al., 2012). Derigs and Illing (2013) presented a model-based evaluation of network optimization for cargo airlines under different EU ETS scenarios. In 2014, the EU summit adopted a 2030 framework for climate and energy; one of its goals is to reduce greenhouse gas emissions by at least 40 percent in 2030 compared to 1990. To achieve this goal, the summit agreed that EU ETS emissions should be reduced by 43% in 2030 compared to 2005. In addition, green fleet management practices have been investigated using case studies to combine vehicle purchases, retrofitting aggregated task assignment decisions (Stasko and Gao, 2010) resale, and retrofit decisions in a fleet setting with stochastic vehicle breakdowns (Stasko and Gao, 2012). The aviation industry is facing significant economic impacts and demands for corporate social responsibility (CSR); these require an evaluation of strategic fleet management. From the above, most of the previous research only focused on the impact of EU ETS on the aviation industry, and on a single effect. Significantly fewer were integrated studies focusing on the four pillars recommended by IATA.

Operations Research (OR) is most often associated with cost minimization and environmental constraints, especially in regard to carbon emission issues (Dekker et al., 2012; Absi et al., 2013). The purpose of this study is to investigate aspects of green aviation fleet management strategy planning. In order to achieve green aviation fleet management efficiency, it is necessary to analyze the interrelationship among various criteria. A combination of rising concerns about the environmental impact of the airline industry has meant that green aviation fleet management programs are becoming focal points of airline business strategies. Airlines have begun to develop thorough methodologies to meet the goal of setting up a green fleet. The MCDM (multi-criteria decision-making) approach is a useful technique widely used in dealing with multi-criteria problems, such as comparative analyses of VIKOR and TOPSIS (Technique for Ordering Preference by Similarity to Ideal Solution) (Oppicovic and Tzeng, 2004, 2007), agricultural information using AHP (Analytic Hierarchy Process) (Kim, 2006), knowledge management strategies combining ANP (analytic network process) and DEMATEL (decision-making trial and evaluation laboratory) (Wu, 2008). In order to determine the requisite decisions and solve the resources-related problems, the major contribution of this paper is to integrate the DEMATEL, ANP and ZOGP (zero-one goal programming) methods to define the best choice of green aviation fleet programs in order to achieve a set of ambitious targets to mitigate CO_2 emissions.

2. Management strategies for green aviation fleet programs

IATA is determined to be part of the solution to achieve targets of reducing CO_2 emissions through the four pillars of the aviation industry strategy. In this study we refer to the IATA four-pillar strategy as the basis for aviation energy conservation's four strategies, and determine factors that impact each strategy, depending on conservation measures in the corporate social responsibility report (CSR) of global large-size airlines. The CSR chosen by the research includes the following airlines: Delta Airlines, the biggest airline in the US; Air France KLM Corporate and British Airways the largest airlines in the two areas China Southern, the biggest airline in China; Cathay Pacific Airways to represent Hong Kong; All Nippon Airways Corporate for Japan; and China Airlines and EVA Airways to represent Taiwan. In addition, we also collected various theses, journals, working papers and other related information, and examined the literature comprehensively to determine the factors of the four criteria and eleven alternatives. A review of the literature is presented in the next section.

2.1. Technology

IATA (2009) proposed a global approach to reducing aviation emissions. According to the approach, technology has the best prospects for reducing aviation emissions of the four pillars. The aviation industry is making great advances in technology such as: revolutionary new plane designs; new composite lightweight materials; radical new engine advances; and the development of biofuels. Airlines will spend $1.5 trillion on new aircraft by 2020. Some 5500 aircraft will be replaced by 2020, or 27% of the total fleet, resulting in a 21% reduction in CO_2 emissions compared to business as usual. Szodruch et al. (2011) indicate that environmental impacts can be substantially reduced by new technology. Developing new technology can improve fuel efficiency and reduce CO_2 emissions. The growth of world air traffic has been accompanied by a significant increase in its environmental impact, including CO_2 emissions, which has forced the European Union to include aviation in its EU ETS (Zanin et al., 2016). The aviation field has done lots of work to improve fuel efficiency through more advanced jet engines, high-lift wing designs and lighter airframe materials (Lee et al., 2001). An aircraft is composed of systems that convert fuel energy into mechanical energy in order to perform work, the movement of people and cargo. An aircraft engine converts a flow of chemical energy contained in aviation fuel and the air drawn into

[1] Data from http://www.iata.org/pressroom/pr/Pages/2016-10-06-02.aspx.

the engine into power (Lee, 2009). Overall engine efficiency is defined by the ratio of power to the total fuel energy flow rate. Only one-fourth to one-third of fuel energy is used to overcome drag and thus propel the aircraft. The remaining energy is expelled as waste heat in the engine exhaust (Birch and Noll, 2004). Therefore, improving engine efficiency can directly improve fuel efficiency. Looking at historical trends, engine efficiency has improved by approximately 40% over the period from 1959 to 1995 due to newly introduced engines (Lee et al., 2001).

Previous studies offered technology related to green aviation fleet management, such as retrofits, fleet renewal and alternative biofuels. Stasko and Gao (2010) developed an alternative integer program model for optimizing fleet replacement strategies under budgets, and allowing for the possibility of conducting retrofits and assigning value to emissions. In fact, the prudent fleet renewal/purchase schedule strategies while holding potential for the aviation sector, also involve inherent risks. Therefore, management must consider direct risks to the supply side, including the future price of fuel, as well as the pricing and regulation of environmental externalities such as global greenhouse gas emissions, local air pollutants and noise. Schaltegger and Csutora (2012) point out that many countries' corporations are being held accountable for their carbon impacts through various forms of environmental legislation, such as supporting the shift to biofuels and other forms of renewable energy, in addition to improved energy efficiency.

IATA considers technology as the best prospect for reducing aviation emissions. Many options for mitigating aviation's environmental impact rely on the introduction of new aircraft technology, retrofits or early retirement of older aircraft (Dray, 2013). IATA provides technology road-maps that identify future technologies which could reduce emissions by 20%–35% per aircraft. In addition to the evolution of the current aircraft platform, hydrogen and ethanol have been proposed as alternative fuels for future low emission aircraft (Veziroglu, 2008). Hydrogen-fueled engines generate no CO_2 emissions at the point of use, may reduce NOx emissions and greatly diminish emissions of particulate matter. However, hydrogen-fueled engines would replace CO_2 emissions from aircraft with a threefold increase in emissions of water vapor. Considering the uncertainties over contrails and cirrus cloud formation, and the radiative impact of water vapor at higher altitudes, it is not clear whether the use of hydrogen would reduce the radiative contribution by aircraft (Kivits et al., 2010; Becken, 2007). Finally, Szodruch et al. (2011) points out that technologies developed today and used in the next generation of aircraft will be decisive in achieving the sustainability of air transport in future decades. Therefore, research and development efforts need to be strengthened and focused on the critical issues and enabling technologies, including education and training efforts for students and young professionals.

2.2. Operation

The Intergovernmental Panel on Climate Change identified 6% inefficiency in aircraft operations. Since 2005, IATA's Green Teams have worked hard with airlines to reduce this inefficiency. Improved operational practices will achieve 3% emissions reductions by 2020. In 2008 IATA's Green Teams saved 11 million tons of CO_2 (IATA, 2009). Therefore, more efficient operations can save fuel and reduce CO_2 emissions. According to several international airlines' CSR reports, they have successfully improved operation efficiency to save fuel. Setting up their differentiated marketing strategies for enhancing environmental protection efforts could prove beneficial for airlines (Niu et al., 2016). Since 2005, the IATA green team has worked with airlines to reduce operational inefficiency and advised airlines on fuel, emissions and energy saving. In 2008, IATA saved 11 million tons of CO_2.

Previous studies have found that operational measures are cost-effective ways to lower the energy intensity of aviation and mitigate subsequent climate effects (Lee, 2010). Lim and Hong (2014) found that, after accounting for the presence of cost inefficiency, fuel-hedging airlines had about 9–12% lower operating costs, but this effect is statistically insignificant. Myhre and Stordal (2001) suggest that shifting the peak traffic periods towards sunrise and sunset could reduce the contrail impact because the amount of solar radiation blocked by the contrails is higher at these times, and acts to cancel the warming effect. An alternative method would be to reduce contrail production by restricting cruising altitudes. The formation of contrails and cirrus clouds can be reduced by reducing flights in air masses that are supersaturated with ice. Sausen et al. (1998) found that changes in the cruising altitude of aircraft could eliminate the contrail contribution, but constraints on cruising altitudes would prevent some aircraft from operating at their maximum speed and efficiency. As a result, the implications for total fuel burn, and hence the radiative impact of increased CO_2, must be considered. Williams et al. (2002) studied these tradeoffs using an air space simulation model as applied to European airspace. Based on a one-day Western European traffic sample, the calculations suggest that annual mean CO_2 emissions would increase by only 4% if cruise altitudes were restricted to prevent contrail formation. The change in flight time depends on aircraft type and route, but average changes are less than 1 min. The cruising altitude change strategy would work immediately if pilots have access to an accurate device that measures relative humidity, and if there is enough flexibility in the selection of flight levels (Mannstein et al., 2005; Schumann, 2005). In addition, proper weight control measures will effectively reduce the consumption of fuel. A gas turbine is the main part of an auxiliary power unit (APU) of an aircraft; when the APU is used, the efficiency will be about half that of the main engines. The combustion of jet fuel in the gas turbine of an APU can release pollutant gases such as nitrogen oxides, hydrocarbons, carbon monoxide, particulate matter, and carbon dioxide (Srinivasan et al., 2006). It is critically important to consider that cost-minimizing transportation replacement strategies should place an increasing emphasis on carbon emission reduction. Management must decide when transportation should be repaired or maintained in uncertain surroundings. Stasko and Gao (2012) propose a model to evaluate repair and maintenance cost minimization. Lastly, Szodruch et al. (2011) stated that the advantage of these operational improvements is that they will immediately affect the whole fleet.

2.3. Infrastructure

In 1999, the Intergovernmental Panel on Climate Change estimated that there was 12% inefficiency in the air transport infrastructure. Since then, 4% increased efficiency has been achieved, but there is still a long way to go. Therefore, infrastructure improvements present a major opportunity for fuel and CO_2 reductions in the short term (IATA, 2009). Oster and Strong (2008) posit that the international Air traffic management system is essential when facing significant challenges to effective communication. The implementation of more efficient Air Traffic Management (ATM) and airport infrastructures could provide additional 4% emissions reduction by 2020. The proposed airport traffic complexity metric quite satisfactorily reflects the influence of traffic characteristics upon the environmental state of the system, and different ATM strategic and tactical measures (airport airfield infrastructure development and applied ATC tactics) could significantly reduce traffic complexity and increase time and environmental efficiency at the airport (Simić and Babić, 2015).

Measures include implementation of the Single European Sky (SESAR), which would produce a 70% cut in route extension; the Next Generation Air Traffic Management system in the USA, which would lead to a 57% reduction in delays; reorganization of the Pearl River Delta ATM system in Hong Kong; reduced vertical separation minima (RVSM) over Russia; and flex tracks. These measures would require investment of $58 billion.

It is important to design a reliable flight route schedule, and transit route design involves a strategic level decision with considerable effects (Beltran et al., 2009; Cipriani et al., 2012). Given a flight route, its schedule design requires an infrastructural level decision to determine flight dispatching frequencies or headways. With respect to the air traffic management planning, Dell'Olmo and Lulli (2003) proposed a two-level hierarchical architecture for air traffic management problems with corresponding mathematical models. A. Agustín et al. (2012) also presented a framework for modeling multistage mixed 0–1 problems for the air traffic flow management with rerouting (ATFMRP) under uncertainty in airport arrival and departure capacity, air sector capacity and flight demand. Cahill et al. (2013) proposed that the preflight, flight planning and briefing tasks are critical both from an operational and a safety/human factors perspective. Under the environmental protection regulations, the simplification of flight procedures must take into account safety, along with the requirements for best practice in communicating with crew, in order to achieve green aviation flight procedure management efficiency.

2.4. Economic performance

IATA (2009) points out that while efforts from the first three pillars will go a long way to achieving the goal of carbon-neutral growth from 2020, it will not be quite enough, at least not initially. To close the gap, we will need to deploy the fourth pillar, economic measures. Absi N. et al. (2013) proposed that emissions trading for international aviation impact operating costs and transport requirements for different airline types. Hence, emission trading is one approach to reducing emissions, whereby each entity in an emissions trading scheme can choose the least costly option to meet its emissions quota, thereby lowering its production, improving its energy efficiency, or buying extra allowances from other entities that emit less than their quota. Thus, the buyer is paying to emit more, while the seller is paid for having reduced its emissions. For aviation to be effective, any emissions trading scheme must have an open architecture, i.e. aviation should have full and unrestricted access to carbon market instruments to meet its obligations, on par with other sectors. The inclusion of aviation emissions in the overall post-Kyoto framework, accompanied by specific reduction targets, should make this possible.

Any revenue from the economic performance of a global scheme to address aviation emissions should be earmarked for environmental purposes. A proportion of such revenues should be reinvested in additional measures to improve the emissions profile of the global aviation sector, for instance by supporting the development and deployment of more fuel-efficient aircraft and sustainable low carbon jet fuels. The balance of such revenues may be used to acquire certified emission reductions from recognized climate mitigation and adaptation projects, provided that the credits are counted towards achieving aviation's sectoral CO_2 reduction targets. The reduction of carbon emission investment has the characteristics of economic change, technology development, etc. Arblaster (2012) identified some aspects of airline influence on investment decisions in ATM and compared industry consultation in Australia with a new consultation process in the UK. Investment decision efficiency in green aviation fleet management assists in developing strategies to bring about the effective use of revenues, and provides a realistic management strategies target for what the aviation industry can achieve.

3. An integrated model for green aviation fleet program management strategies

Tzeng et al. (2007) showed that DEMATEL can enhance our understanding of complex problems that involve different dimensions, as well as identify feasible solutions within hierarchical structures. The DEMATEL method is one of the tools used for multiple criteria decision making and is able to transform qualitative issues into quantitative tasks for analysis (Gabus and Fontela, 1973). Goal programming is designed to deal with problems involving multiple conflicting objectives, but lacks a systematic approach to set priorities and trade-offs among objectives and criteria (Reza et al., 1988). The DEMATEL results are introduced into ANP to obtain the weight of each program. The ANP method is a systematic procedure for evoking the interviewees' group opinions. To structure a network model for green fleet program selection, DEMATEL is useful for picturing an uncertain framework of a network structure that has interdependent relationships among the criteria; ANP is applied to overcome this problem (Saaty, 1996). The ZOGP model can handle the MCDM problem and attain the objectives of an organization, while considering restricted resources. Therefore, the ZOGP model with priorities set by ANP is very useful when making the selection decision of CSR programs under limited resources and constrained situations (Tsai et al., 2010). Lupo (2015) proposed a new approach to comparatively evaluate the quality of service alternatives. In particular, a fuzzy extension of the ServPerf service conceptual model was considered to estimate quality scores of fundamental service criteria, whereas the non-compensative multi-criteria decision-making ELECTRE III method was employed to point out the quality ranking of service alternatives, on the basis of which the comparative service quality analysis was performed. Therefore, an integrated model will be applied in choosing the optimal green aviation fleet programs. This study first applies the DEMATEL method to investigate interactive relationships between criteria. The incorporated ANP method is then employed to evaluate the relative importance of relevant factors; it is schematically shown in Fig. 1 and explained in the following subsections.

3.1. DEMATEL method

The DEMATEL technique has been applied to many decision-making issues, including: CO_2 capture and storage criteria evaluation (Quader et al., 2015), sustainable development (Tsai et al., 2009), improving transportation service quality (Liou et al., 2014), recycled material vendor selection (Hsu et al., 2012), improving metro-airport connection service for tourism development (Liu et al., 2013), and so on. In order to construct a hybrid model of green aviation fleet programs, we need to understand the level of interaction and self-feedback relationships among the criteria or sub-criterion factors. The DEMATEL method is a potent method that helps to gather group knowledge for forming a structural model, as well as to visualize the causal relationships of sub-systems through a causal diagram. This study uses the DEMATEL method to derive the relationships and their degrees of interdependence among green fleet criteria. Using comparisons of pairs of dimensions, the degrees of perceptions from the interviewees regarding the level of impact of particular dimensions are examined. The measurement criteria of 0, 1, 2, 3 and 4 are used to represent no influence, low influence, medium influence, high influence and very high influence, respectively. $X=\{X_1, X_2, \ldots, X_n\}$ is a set of nodes (available alternatives) for which particular pair-wise relations are

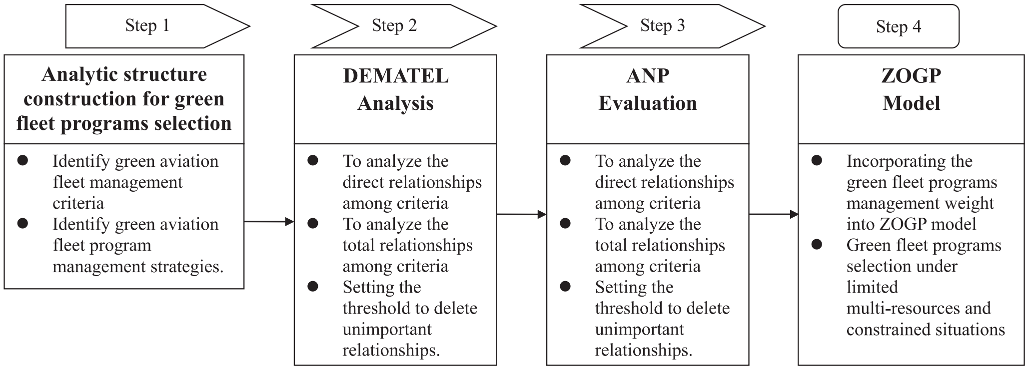

Fig. 1. A hybrid model of a green aviation fleet program choice.

determined. An n × n preliminary matrix V with directly observed relations is obtained, in which t_{ij} denotes the degree of impact of the i factor on the j factor. Accordingly, all principal diagonal elements, v_{ij}, of matrix X are set to zero. There are two methods for calculating a normalized direct relation matrix. Wu and Lee (2007), Lin and Wu (2008), Kim (2006), Wu (2012) and Seyed-Hosseini et al. (2006) used the maximum sum of row vectors as the standard for normalization, while Tzeng et al. (2007) employed the maximum sum of row or column vectors. Composing the normalized matrix, which can be derived from Eqs. (1) and (2), the matrix diagonal is coded 0 and the sum of each row and column does not exceed 1:

$$X = s \times V \tag{1}$$

$$s = \frac{1}{\underset{1 \le i \le n}{Max} \sum_{j=1}^{n} v_{ij}} \quad i,j = 1,2,\ldots,n. \tag{2}$$

According to Goodman (1988) and Papoulis and Pillai (2002), the total-relation matrix T can be acquired by using Eq. (3), in which the I is denoted as the identity matrix:

$$T = \lim_{k \to \infty} \left(V + V^2 + \cdots + V^k \right) = V \times (1 - V)^{-1} \tag{3}$$

Provided that t_{ij} is a variable of the direct/indirect relation matrix *T*, where i, j = 1, 2, …, n, from Eqs. (4) and (5), the sum of row and column in the direct/indirect relation matrix T can be calculated. D_i is the sum of row i, representing variable I, which is the factor affecting the sum of other variables; R_j is the sum of column j, representing the sum affected by other variables with variable i as the result. Both D_i and R_j obtained from the direct/indirect relation matrix T account for the direct and indirect influences:

$$D_i = \sum_{j=1}^{n} t_{ij} \tag{4}$$

$$R_j = \sum_{i=1}^{n} t_{ij} \tag{5}$$

A threshold value for the influence level is needed to map the relationships between alternatives. A causal diagram can be obtained by mapping the dataset of (D + R, D-R), where the horizontal axis (D + R) is made by adding D to R, while the vertical axis (D-R) is made by subtracting D from R. Only certain elements that have an influence level in t above the threshold are chosen and used for the maps. The threshold value is decided externally with D_k-R_k indicating the strength of the influence for each alternative (Tzeng and Huang, 2012). Alternatives with higher values of D_k-R_k are assumed to have greater priority and are called dispatchers; those with lower values are receivers (Asgharpour, 2001). Alternatives with a higher $D_k + R_k$ have a stronger relationship with others. In practice, D_k-R_k values are more effective and applicable than are $D_k + R_k$ values.

3.2. Analytic network process (ANP) method

ANP is the most comprehensive framework available to the decision-maker today for analyzing social, governmental and corporate decisions. Rather than a strict linear, top-to-bottom hierarchy, the model provides a loose network structure representing a real-world decision. The relative strength of each effect on a given element is measured as a ratio (Shyur, 2003). ANP has two stages. The first is a control hierarchy or network of objectives and criteria that control the interactions in the system being studied; the second includes the many sub-networks of influences among the elements and clusters of the problem, one for each control criterion. Let W_{GaCr} be a vector that presents the impact of the goal on the criteria, W_{CrCr} be a matrix that represents the impact between each criterion, W_{CrAl} be a matrix that represents the impact of the criteria on each of the alternatives, and I be the identity matrix. Then, the super-matrix of a hierarchy with three levels is shown in the following equation. Let G_a = Goal, C_r = Criteria and A_l = Alternatives; then we can show *W* as follows:

$$w = \begin{array}{c} \\ G_a \\ C_r \\ A_l \end{array} \begin{array}{c} \begin{array}{ccc} G_a & C_r & A_l \end{array} \\ \begin{pmatrix} I & 0 & 0 \\ W_{G_aC_r} & W_{C_rC_r} & 0 \\ 0 & W_{C_rA_l} & I \end{pmatrix} \end{array} \tag{6}$$

Saaty (1996) proposed utilizing the consistency index (CI) and consistency ratio (CR) to verify the consistency of the comparison matrix. CI and CR are defined as follows:

$$CI = \left(\frac{\lambda_{\max} - n}{n - 1} \right) \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

where $\lambda_{\max}$ is the largest eigenvalue of the pairwise comparison matrix, n denotes the numbers of attributes (orders) and RI indicates the average consistency index over numerous random entries of the reciprocal matrices with the same orders. For n = 1–10, the corresponding RI values are 0, 0, 0.58, 0.9, 1.12, 1.24, 1.32, 1.41, 1.45 and 1.49, respectively. If CR ≤ 0.1, the estimate is accepted;

otherwise, a new comparison matrix is solicited until CR≤ 0.1. This study applies Super Decision 6.0 software (Saaty, 2003) to calculate the priorities of CSR programs' alternatives.

3.3. Zero-one goal programming (ZOGP) model

The ZOGP model used the set priorities by ANP as follows:

$$\begin{aligned}
&\text{Minimize} \quad Z = P_i\left(w_j d_i^+, w_j d_i^-\right)\\
&\text{Subject to} \quad \sum_j a_{ij}x_j + d_i^- - d_i^+ = b_i \quad \text{for} \quad i = 1,2,\dots,m; \quad j = 1,2,\dots,n\\
&\qquad x_j + d_r^- = 1 \quad \text{for} \quad r = m+1, m+2, \dots, m+n; \quad j = 1,2,\dots,n\\
&\qquad d_i^+ \geq 0,\ d_i^- \geq 0 \quad \text{for} \quad \forall_i\\
&\qquad x_j = 0 \text{ or } 1 \quad \text{for} \quad \forall_j
\end{aligned}$$

where Z denotes the sum of the deviation from m goals considered; n is the pool of green aviation fleet programs from which the optimal programs are selected; P_l is a preemptive priority ($P_1 > P_2 > P_3 >>> P_l$) for goal l; d_i^+ and d_i^- are the positive or negative deviation variables for the selection criterion i; w_j is the ANP weight on the j_{th} green fleet program; a_{ij} is the green fleet program parameter j of selection resource i; b_i is the available resources considered in the selection decision; and x_j is the binary variable.

4. An illustrative application for selecting green aviation fleet programs

In Taiwan, there are five major international airlines. Each company has a department in charge of environmental affairs. For this study, two questionnaires were issued to each company's environmental affairs project managers; it includes 10 airline managers involved in green aviation fleet programs. The average seniority of respondents is more than 20 years. Participants were asked to specify the objectives that their corporation should pursue when allocating resources among green fleet programs. After the DEMATEL inquiry, four criteria and 11 green fleet program candidates were specified. The first step was to design the two levels that measure the relationships among problematic factors. The measurement criteria of 0, 1, 2, 3 and 4 were used to represent no influence, low influence, medium influence, high influence and very high influence, respectively. Here, the scores 0, 1, 2, 3 and 4 represent levels of influence ranging from no influence at all to a high influence. Then, pairwise comparisons were determined in order to model a mathematical matrix. The criteria are: technology (TE), operation (OP), infrastructure (IN) and economic performance (EP). Once the relationships between those criteria had been measured by the interviewee panel, the initial direct-relation matrix could be obtained (as shown in Table 1). Based on the initial direct-relation matrix, the normalized direct-relation matrix was obtained using DEMATEL (as shown in Table 2).

Next, the relation matrix T, and D and R values (shown in Table 3) were found. After deciding on the threshold value from

Table 1
The initial direct-relation matrix of four criteria.

	Technology(TE)	Operation (OP)	Infrastructure (IN)	Economic Performance (EP)
TE	0.0	2.8	2.3	2.2
OP	1.2	0.0	1.5	2.5
IN	2.8	2.7	0.0	2.5
EP	2.3	2.7	3.0	0.0

Table 2
The normalized direct-relation matrix of four criteria.

	TE	OP	IN	EP
TE	0.000	0.347	0.286	0.265
OP	0.143	0.000	0.184	0.306
IN	0.347	0.327	0.000	0.306
EP	0.286	0.327	0.367	0.000

Table 3
The total-relation matrix T and prioritization of four criteria.

	TE	OP	IN	EP	D	Order	D + R	Order	D-R
TE	1.321	1.892	1.634	1.695	6.543	EP	13.6073	IN	0.8506
OP	1.150	1.257	1.249	1.378	5.034	IN	13.2754	TE	0.7240
IN	1.689	2.011	1.527	1.837	7.063	TE	12.3617	EP	0.5675
EP	1.659	2.016	1.803	1.609	7.087	OP	12.2105	OP	−2.1420
R	5.819	7.176	6.212	6.520					

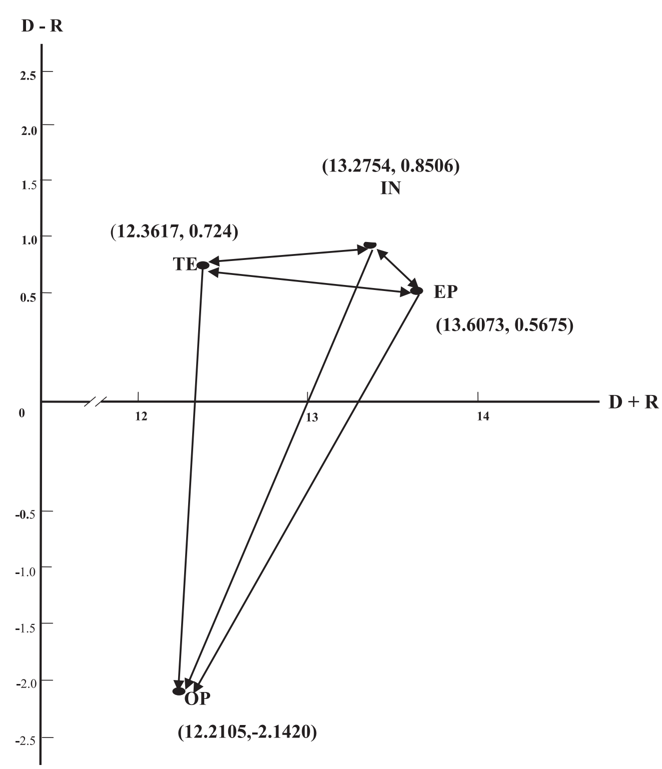

Fig. 2. Relationships between four green aviation fleet criteria.

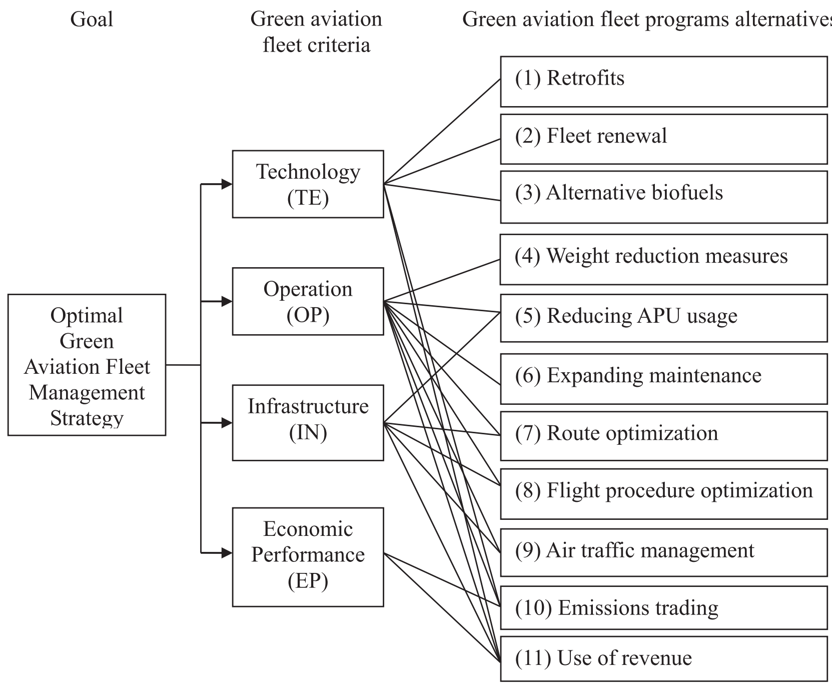

Fig. 3. ANP framework of a green aviation fleet program selection.

interviewees through discussion, the relationships between alternative maps was found by mapping a dataset of D + R and D-R (shown in Fig. 2). The IN criterion with the highest value of D-R is prior to the others, and is called the master dispatcher. The OP criterion with the lowest value of D-R is a master receiver. The results indicate that the IN criterion is a major influence on other criteria in pursuing green fleets by these airline companies. Furthermore, the OP criterion is only affected by other criteria. The EP criterion with the highest value of D + R has the most relationships with others.

Eleven alternative green aviation fleet programs were considered: retrofits, fleet renewal, alternative biofuels, weight reduction measures, reducing APU (auxiliary power unit) usage, expanding maintenance, route optimization, flight procedure optimization, air traffic management, emissions trading and use of revenue.

This study used ANP to set priorities among the programs. The interdependence among the four criteria and the hierarchical framework of the ANP are shown in Fig. 3. DEMATEL and ANP are combined for decision making in acquiring green aviation fleet program priority weights. The interviewee groups were asked to provide their value judgments in the pair-wise comparison matrix and the elements of the overall matrix were then obtained by the numerical average of the corresponding elements to arrive at a final priority with all columns summing to unity (Saaty, 2003). The results of the ANP phase are shown in Table 4 for each green aviation fleet program alternative. The largest weight was assigned to the emissions trading program, followed by the expanding maintenance program. Alternative biofuels and route optimization had the lowest weights. These weights were used as priorities in goal programming formulation.

After finding the priority weights for each green fleet program, the airline optimizes selection decisions under organizational goals and resource restrictions. This study takes an example of 'C Airlines' (which for confidentiality reasons is not identified). C Airlines has founded more than 50 years ago, is actively involved in environmental management, energy saving and carbon reduction, and fulfills its social responsibility. Since 2009 C Airlines has continued its Fuel Efficiency Gap Analysis project. In 2009 the Company implemented ISO 14,064–1. According to the EU ETS directive, the Company declared two copies of monitoring plans to the government of Holland (NEa), and was examined by NEa in 2009. In 2010 the Company also installed the EU environmental protection research unit (In-service Aircraft for a Global Observing System) on an A340. The flight data of atmospheric gases are automatically collected for the domestic and foreign research units to understand the high-altitude air changes as a reference for research on ecological protection. This study took the Company as a case study. It has four obligatory goals: remaining within a budget of $6 billion; 20,000 h of annual consultants' time; 40,000 h of training; and an initial allocation of labor hours of 20,000 h. Table 5 shows the limitations on green fleet program choice, where X_j are the alternatives and binary variables; if $X_j = 1$, then the j_{th} program is selected; if $X_j = 0$, it is not. The quantity of resources i_{th} required for the j_{th} program is represented by a_{ij}, and b_i is the resource

Table 4
The results of the ANP phase are the priority weights for each green fleet program alternatives.

Green aviation fleet criteria	Green aviation fleet Programs alternatives	Priority weights	Ranking
Technology (TE) 0.14	(1) Retrofits	0.0768	6
	(2) Fleet renewal	0.0421	9
	(3) Alternative biofuels	0.0357	11
Operating (OP) 0.25	(4) Weight reduction measures	0.0949	5
	(5) Reducing APU usage	0.1035	4
	(6) Expanding maintenance	0.1602	2
Infrastructure (IN) 0.49	(7) Route optimization	0.0376	10
	(8) Flight procedure optimization	0.0432	8
	(9) Air traffic management	0.0642	7
Economic Performance (EP) 0.12	(10) Emissions trading	0.1833	1
	(11) Use of revenue	0.1586	3

Table 5
The resource requirements and obligatory limitations of green aviation fleet programs choice.

The resource requirements of the eleven green aviation fleet programs (a_{ij})				
	Budget amounts (million dollars)	Consultant hours (h)	Training hours (h)	Labor hours (h)
X_1	1800	5700	18,300	4300
X_2	3000	7300	4300	1900
X_3	1200	3700	700	700
X_4	540	1300	700	500
X_5	420	900	700	700
X_6	420	900	14,300	8300
X_7	360	700	1100	2300
X_8	360	900	1100	2700
X_9	360	700	700	500
X_{10}	420	500	700	700
X_{11}	420	700	700	700
b_i(Max.)	6000	20,000	40,000	20,000
b_i(Min.)	4000	–	–	–

Table 6
Goal programming formulation model for green fleet programs.

$$\text{Minimize } Z = \{p_1(d_1^+ + d_2^+ + d_3^+), p_2(0.0768d_4^- + 0.0421d_5^- + 0.0357d_6^- + 0.0949d_7^- + 0.1035d_8^- + 0.1602d_9^- + 0.0376d_{10}^- + 0.0432d_{11}^- + 0.0642d_{12}^- + 0.1833d_{13}^- + 0.1586d_{14}^-), p_3(d_{15}^- + d_{15}^+), p_4(d_{16}^- + d_{16}^+)\} \quad (1)$$

Subject to:

$$1{,}800X_1+3{,}000X_2+1{,}200X_3+540X_4+420X_5+420X_6+360X_7+360X_8+360X_9+420X_{10}+420X_{11}+d_1^- - d_1^+ = 6000 \quad (2)$$
$$5{,}700X_1+7{,}300X_2+3{,}700X_3+1{,}300X_4+900X_5+900X_6+700X_7+900X_8+700X_9+500X_{10}+700X_{11}+d_2^- - d_2^+ = 20{,}000 \quad (3)$$
$$18{,}300X_1+4{,}300X_2+700X_3+700X_4+700X_5+14{,}300X_6+1{,}100X_7+1{,}100X_8+700X_9+700X_{10}+700X_{11}+d_3^- - d_3^+ = 40{,}000 \quad (4)$$
$$X_1+d_4^- = 1 \quad (5)$$
$$X_2+d_5^- = 1 \quad (6)$$
$$X_3+d_6^- = 1 \quad (7)$$
$$X_4+d_7^- = 1 \quad (8)$$
$$X_5+d_8^- = 1 \quad (9)$$
$$X_6+d_9^- = 1 \quad (10)$$
$$X_7+d_{10}^- = 1 \quad (11)$$
$$X_8+d_{11}^- = 1 \quad (12)$$
$$X_9+d_{12}^- = 1 \quad (13)$$
$$X_{10}+d_{13}^- = 1 \quad (14)$$
$$X_{11}+d_{14}^- = 1 \quad (15)$$
$$1{,}800X_1 + 3{,}000X_2 + 1{,}200X_3 + 540X_4 + 420X_5 + 420X_6 + 360X_7 + 360X_8 + 360X_9 + 420X_{10} + 420X_{11} + d_{15}^- - d_{15}^+ = 4000 \quad (16)$$
$$4{,}300X_1 + 1{,}900X_2 + 700X_3 + 500X_4 + 700X_5 + 8{,}300X_6 + 2{,}300X_7 + 2{,}700X_8 + 500X_9 + 700X_{10} + 700X_{11} + d_{16}^- - d_{16}^+ = 20{,}000 \quad (17)$$
$$X_j = 0 \text{ or } 1, j = 1, 2, \ldots, 11$$

Formulation results $X_4 = X_5 = X_9 = X_{10} = X_{11} = 1, X_1 = X_2 = X_3 = X_6 = X_7 = X_8 = 0$
$d_1^- = 3,840, d_1^+ = 0, d_2^- = 15,900, d_2^+ = 0, d_3^- = 500, d_3^+ = 0, d_4^- = 1, d_5^- = 1, d_6^- = 1, d_7^- = 0, d_8^- = 0, d_9^- = 1, d_{10}^- = 1, d_{11}^- = 1, d_{12}^- = 0, d_{13}^- = 0, d_{14}^- = 0,$
$d_{15}^- = 1,840, d_{15}^+ = 0, d_{16}^- = 16900, d_{16}^+ = 0$

constraint. ANP and ZOGP are combined for decision making to select green fleet programs.

The resource requirements and essential limitations of green aviation fleet management strategy are shown in Table 5. The ZOGP model uses LINGO 13.0 software. The formulation results are summarized in Table 6. In formulation (1), p represents the preemptive priority. Eq. (2) limits the maximum budget amounts (in $ 1,000,000), Eq. (3) limits maximum consultant hours, Eq. (4) limits maximum training hours, Eq. (17) limits maximum labor hours and Eq. (16) limits minimum budget amounts (in $1,000,000). Eqs. (5)–(15) represent the selection of green fleet programs. The results are shown in Table 6. Five programs were chosen in the period of green fleet implementation along the lines of the priorities of the organizations' objectives (weight reduction measures, reducing APU usage, air traffic management, emissions trading and use of revenue).

5. Discussion and conclusions

IPCC points out that approximately 25% of global greenhouse gas results from the transport industries, and the aviation industry accounts for 13% of the total transport industry's emissions. In order to achieve a set of ambitious targets to mitigate CO_2 emissions from air transport, this study offers an integrated approach to aid the airline industry in its decision making in regard to green aviation fleet programs. Providing a practical application for selecting a green fleet contributes to setting up a hybrid model for meeting green fleet goals. The results show that an emissions trading program is the major factor for meeting green fleet goals, followed by expanding the maintenance program without any resource requirements and obligatory limitations of the green fleet programs choice. This study took C Airlines as a case study with resource restrictions. The results show that five programs satisfy green aviation fleet goals. Our findings imply that the airline industry should put effort into the following green aviation fleet activities: emissions trading, weight reduction measures, reducing APU usage, and air traffic management, among these, the most attention should be paid to emissions trading. This result is consistent with the current trend of enhancing environmental management, energy saving and carbon reduction, as well as the EU ETS (Emissions Trading Scheme Directive) to aviation, which offers the solution of emissions trading for carbon reduction.

The main contribution of the paper is benefitting academia and industry by providing a new way to integrate DEMATEL, ANP and ZOGP (zero-one goal programming) methods into green aviation fleet project selection.

(1) For the academic field, this study is concerned with the incorporation of CO_2 emissions mitigation and cost measurement into resource constraints content, utilizing an MCDM model integrating the DEMATEL, ANP and ZOGP approaches to arrive at optimal green aviation fleet management strategy decisions. The proposed approach is the first to integrate both the scientific method and the 'competitive advantage' concept to make green aviation fleet selections.
(2) For the industrial field, the integrated model can help airlines project managers accurately understand how to allocate resources and obtain the final optimal portfolio for a sustainable green aviation fleet when resources are limited. This approach can help airline managers make green aviation fleet decisions through scientific techniques and interdependent criteria, as well as with limited resources. The model developed can be applied more widely to green aviation fleet management in various situations.

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